Some Tools for Integrated Modeling and Simulation

Mike Lieber

Ball Aerospace

21 Jan 1998

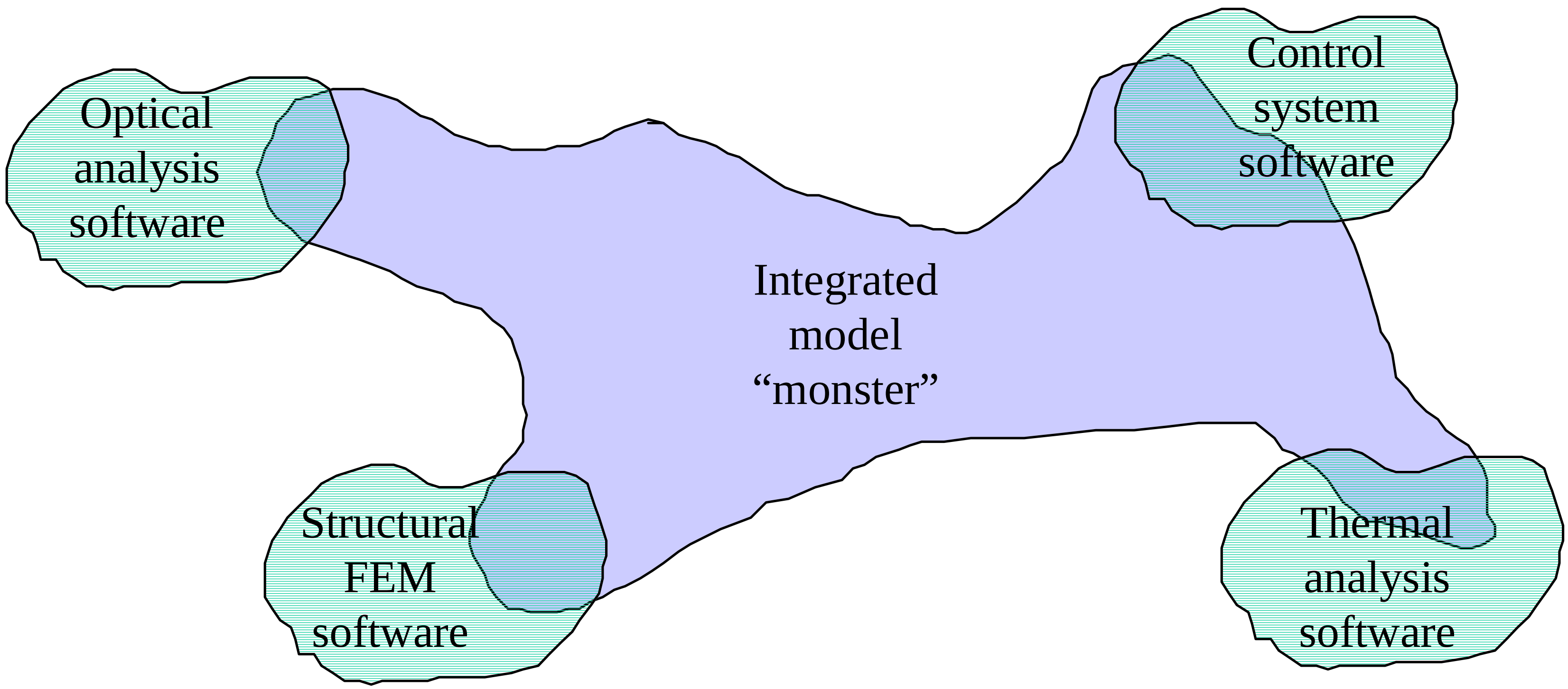
Integrated Modeling Heritage at Ball Aerospace

- Integrated Modeling and Simulation Lab (IMSL) developed optics/structures/ controls/ sensors/ signal processing tools in early 1990's
- Co-development with ESO - KHOROS/MATLAB time simulation model of 8m VLT unit telescope
  - actuated primary
  - disturbance models
  - coupled structures/optics/controls
  - signal processing
- Current integrated modeling for NGST, interferometers, and laser-based programs

Some Tools for Integrated Modeling and Simulation

- Keyword is "Integrated"
- Requires interface with many software tools and "pushing back" boundaries between disciplines
  - Example: Mass/stiffness versus eigenproperties
- Traditional "bucket brigade" approach of handoff between disciplines inefficient and neglects <u>total</u> system aspects.
- New problem - With powerful tools like Simulink user can create incorrect answers faster than ever.
- Individual disciplines get to participate more at system level than before.

Integrated Modeling Requires Carving Some Pieces Out of Traditional Analysis Packages



- But individual disciplines get to participate more at system level than before.

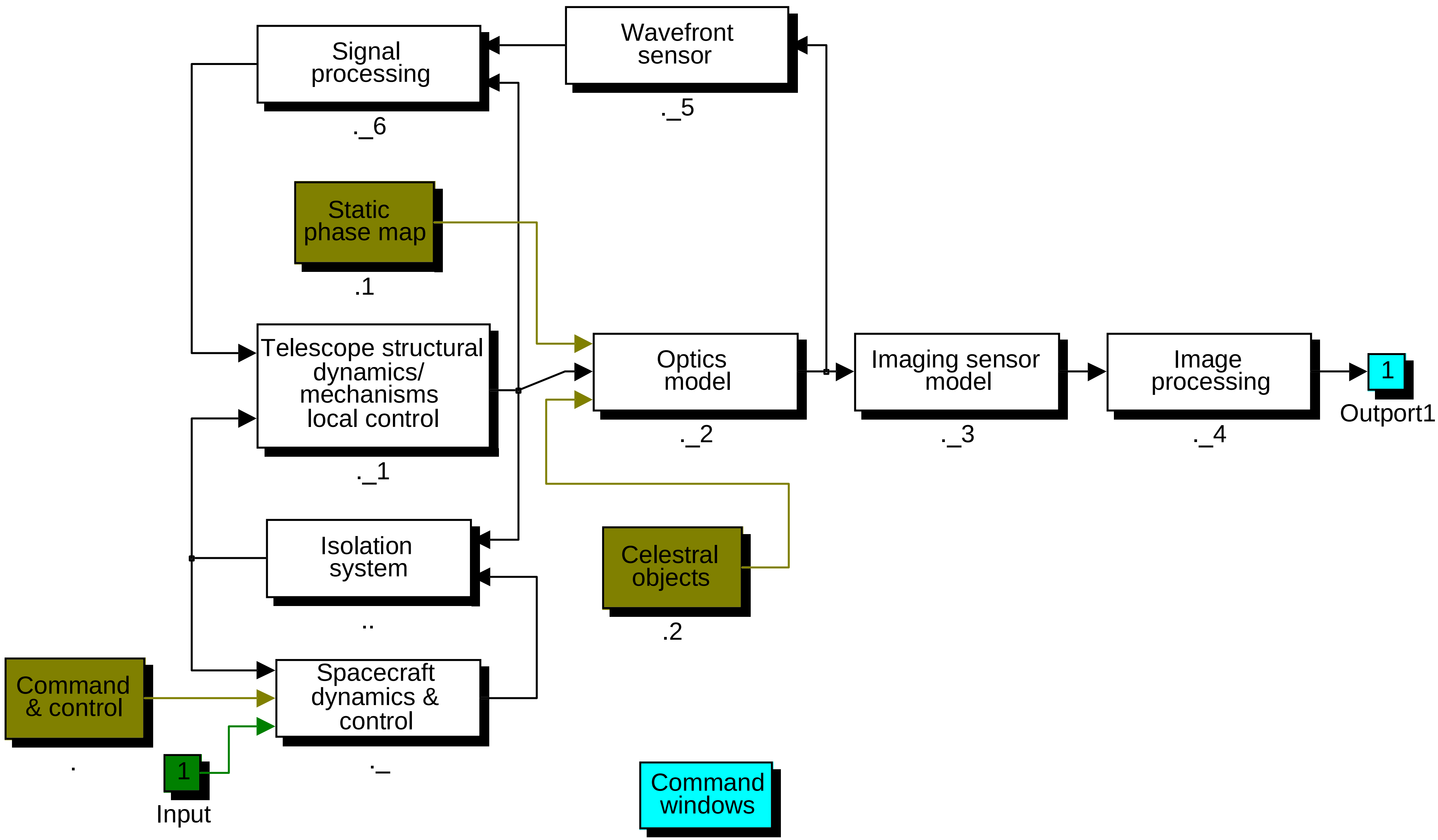
Subsystem Models From Hardware Experience and Large Scale modeling

- Hardware
  - Spacecraft bus
  - Spacecraft instruments
  - Cryogenics
  - Pointing, tracking, stabilization systems

•Large-scale modeling

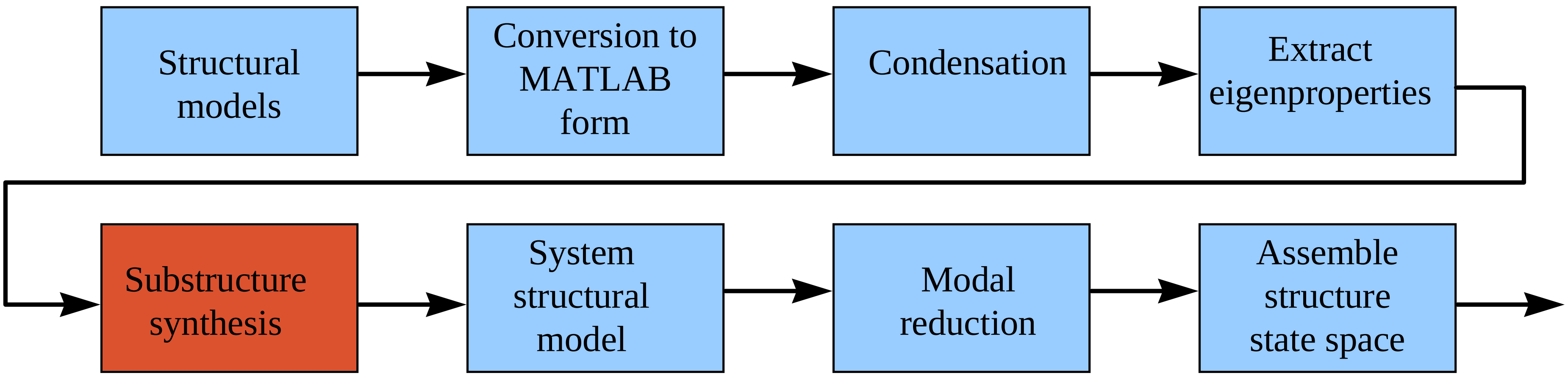
- Active optics
- Wavefront sensors, signal processing, and control algorithms
- Disturbance models
- Model reduction
  - temporal (modal)
  - spatial (nodal)
- Regriding tools
- System assembly
- Ray tracers, diffractive analysis
- Detector models, image analysis
- Noise models, spatial & temporal
- Automated control design
- Adaptive optics
- Spacecraft ACS models

Simulink-based System Model



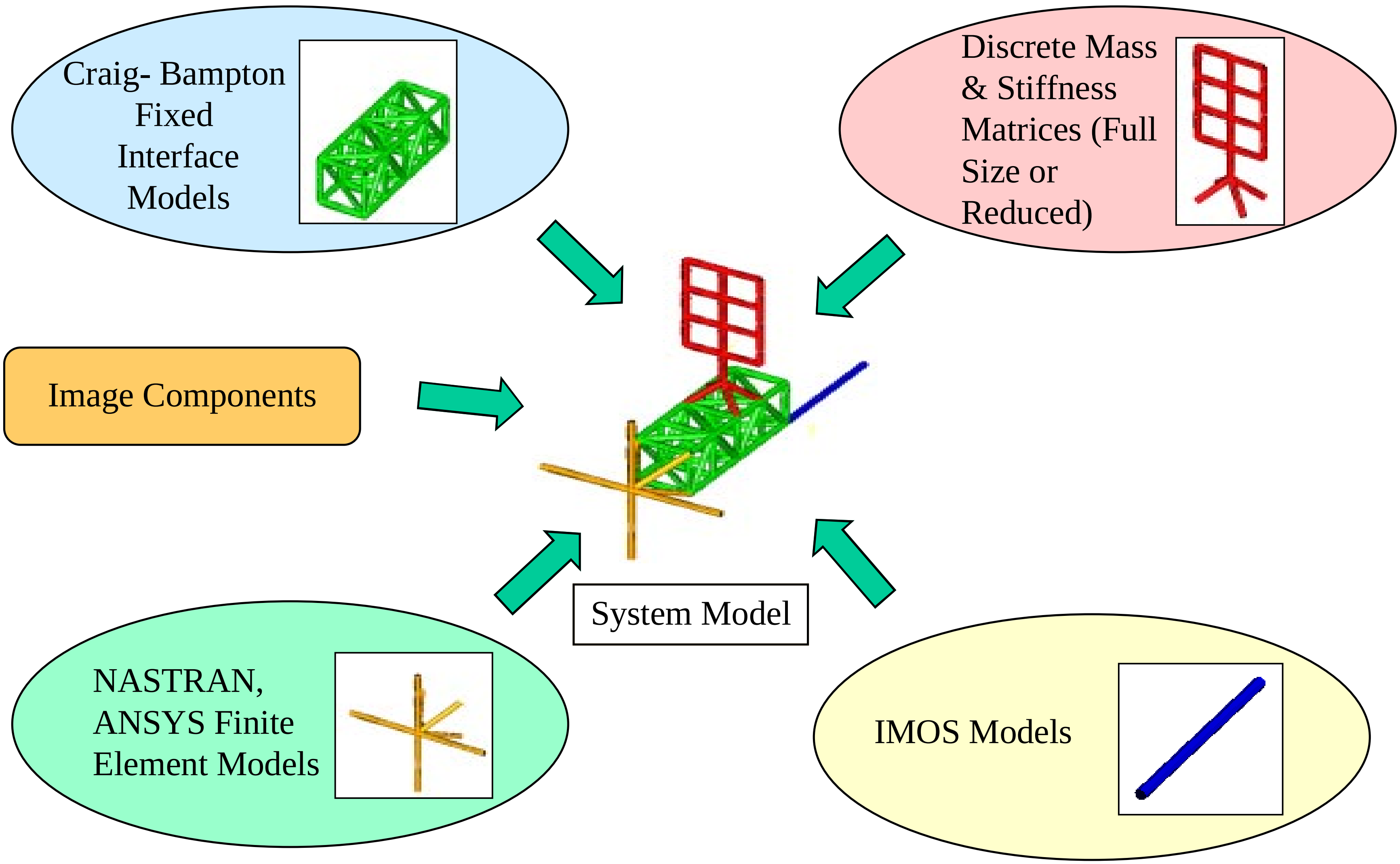
Handling Structural FEM Models

•Multiple structural models, different sources (IMOS, NASA, internal) different designs and changing designs



- Key missing link is substructure synthesis
- Model reduction with Modal Cost Analysis (Skelton), area in general “fiddlers paradise”.

Structural Modeling Process



Component Mode Synthesis

- **Two Step Process**

  (a) Definition of Component Models

  (b) Synthesis of Components Into System Models

- **(a) - Begin With the Component Equations of Motion**

  $$m\ddot{x} + c\dot{x} + kx = f$$

- **Transform the Component Physical Coordinates to a Set of Generalized Coordinates.**

- $x = \Phi q$

  Where x is a Transformation Matrix of Selected Component Modes:

  - Normal Modes (Constrained or Not*)
  - Constraint Modes
  - Rigid Body Modes*
  - Attachment Modes*
  - Inertia relief Modes*
  -

  * - Denotes Enhancements Not Included in the Initial Modeling Effort

Component Mode Synthesis (Cont.)

- Transform Component Equations of Motion into Generalized Coordinates.
- $M\ddot{q} + C\dot{q} + Kq = \Phi^T F$

  - where $M = \Phi^T m \Phi$, $C = \Phi^T c \Phi$, $K = \Phi^T k \Phi$
- (b) Couple the System. Constraint Equations between the components are then formed for the Generalized Coordinates and the interface forces.
- Therefore $x_{ia} = x_{ib}$ and $\Phi_{ia} q_a = \Phi_{ib} q_b$ $f_{ia} + f_{ib} = 0$

  - where

    i - denotes interface generalized coordinates

    a,b - denote individual components
- The constraint equations are then used to generate a transformation matrix which eliminates the dependent coordinates and synthesizes the system model in system generalized coordinates.

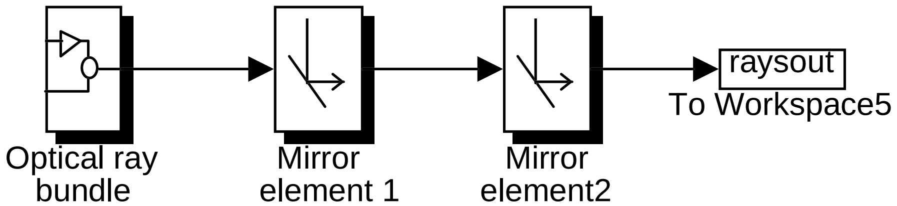
Component Mode Synthesis (Cont.)

- **Comments / Observations**
  - Initial Modeling Effort Utilizes "Craig-Bampton" Fixed Interface Coupling, Later Enhancements May Incorporate Other Coupling Techniques ("Craig-Chang", "Hruda-Benfield", Etc.)
  - Small Displacement Linear Models Are Assumed in Initial Effort.
  - Coupled Damping Has Not Been Implemented.
  - Modal Truncation of Component and System Modes Affect the Accuracy of the Results (May Need to Use Alternate Coupling Technique).
  - Constraint Equations Will Be Generated by the Software Based on Geometric Location, and Will Be Verified by the End User.
  - Software Will Couple Finite Element Models (NASTRAN), Discrete Mass and Stiffness Matrices (Full and Reduced), "Craig-Bampton" Fixed Interface Mass and Stiffness Models, IMOS Models. Future Enhancements Will Accommodate Free Interface Normal Mode Models With and Without Attachment Modes.
  - Software Will Accept Image Components.

Features of Simulink-based Optics Package

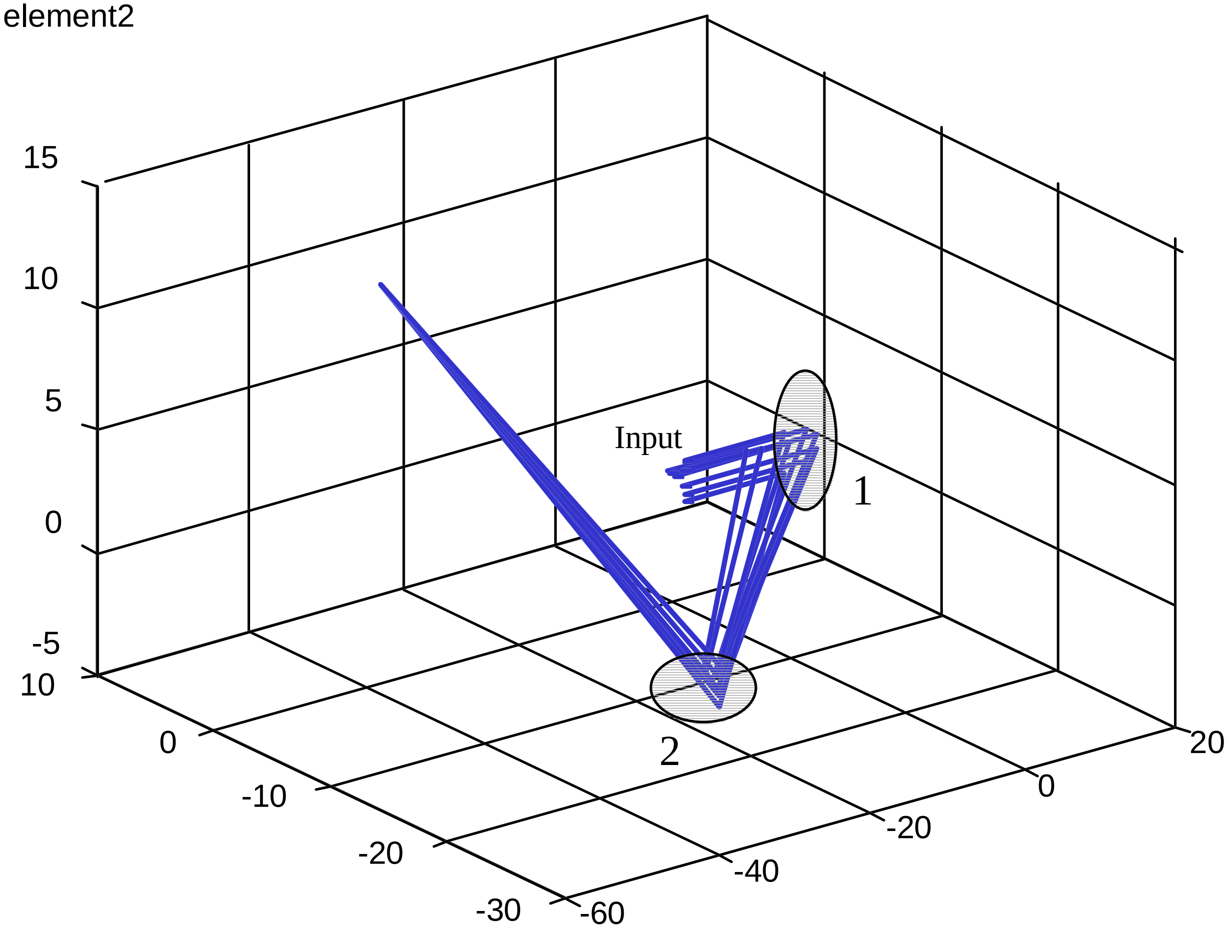
- MATLAB-based geometric and diffractive optics
- Embedded in Simulink environment for rapid prototyping and sensitivity matrix generation
- But… is too slow in current form to use for time simulations.
- Doesn’t have full functionality of MACOS
  - Ray bundle generation, reflective and refractive optics, perturbation analysis and structural inputs, OPD analysis, graphical displays, Zernike aberations, diffractive analysis

Optical Models Resident in Simulink

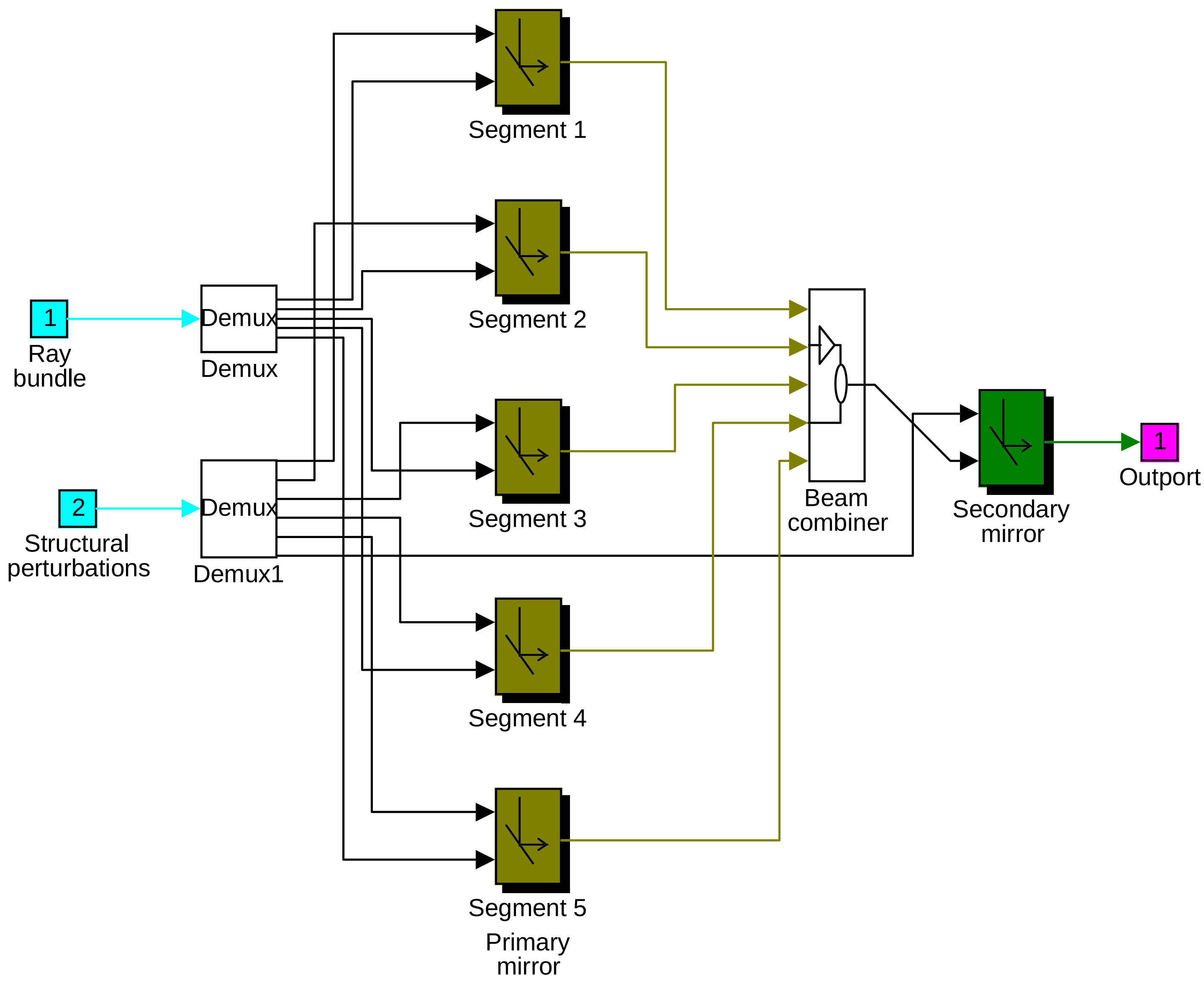


Simulink graphical objects

Ray bundle traced through a two mirror optical system



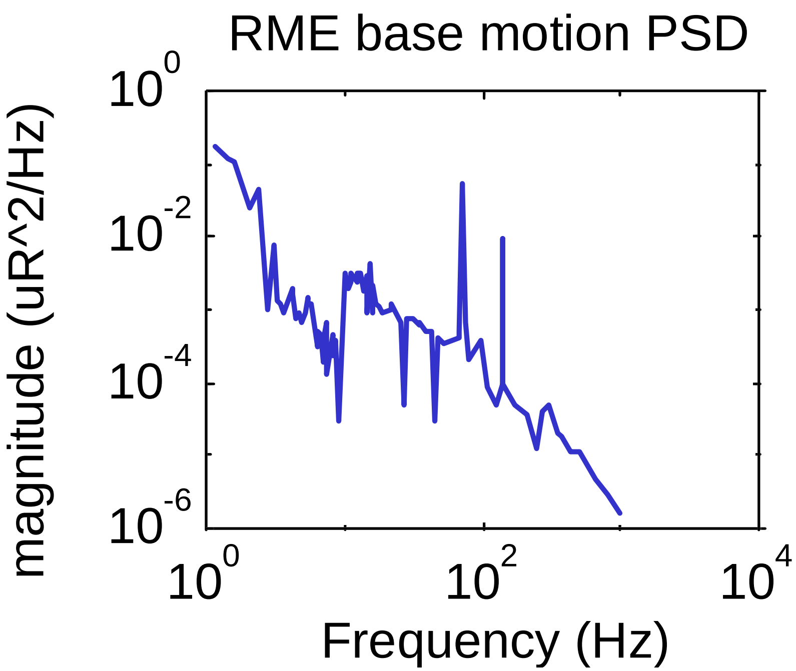
Ray Trace Off Segmented Primary Mirror

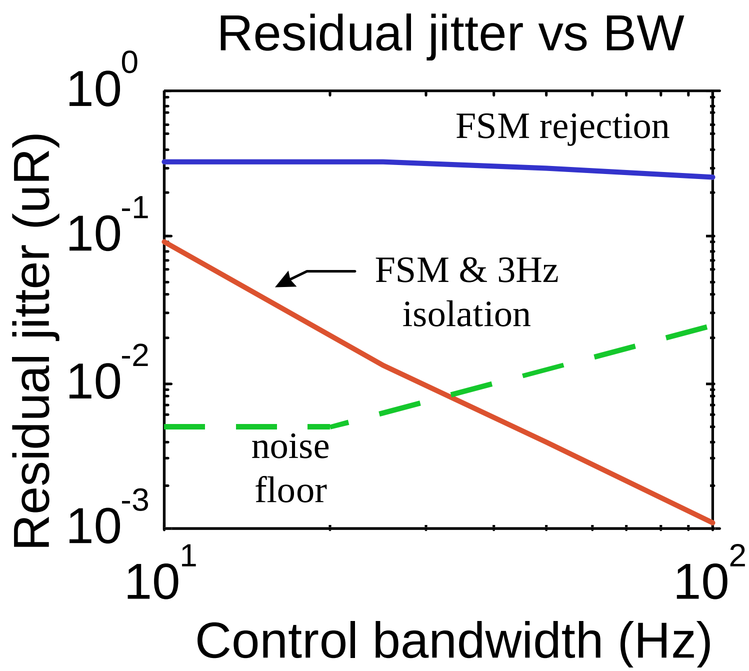


Automated Control System Design

- NGST, SIM and other complex optical systems have many control systems
- Rapid evaluation of system performance as a function of controller performance
- Methodology - combine results from optimal control with algebraic synthesis
- MATLAB-based tool designs 2-DOF servo controller with user input of bandwidth and mass properties
- 2-DOF structure for independent tuning of disturbance rejection and command following

Parametric Study of Control Bandwidth Effect on Residual Jitter



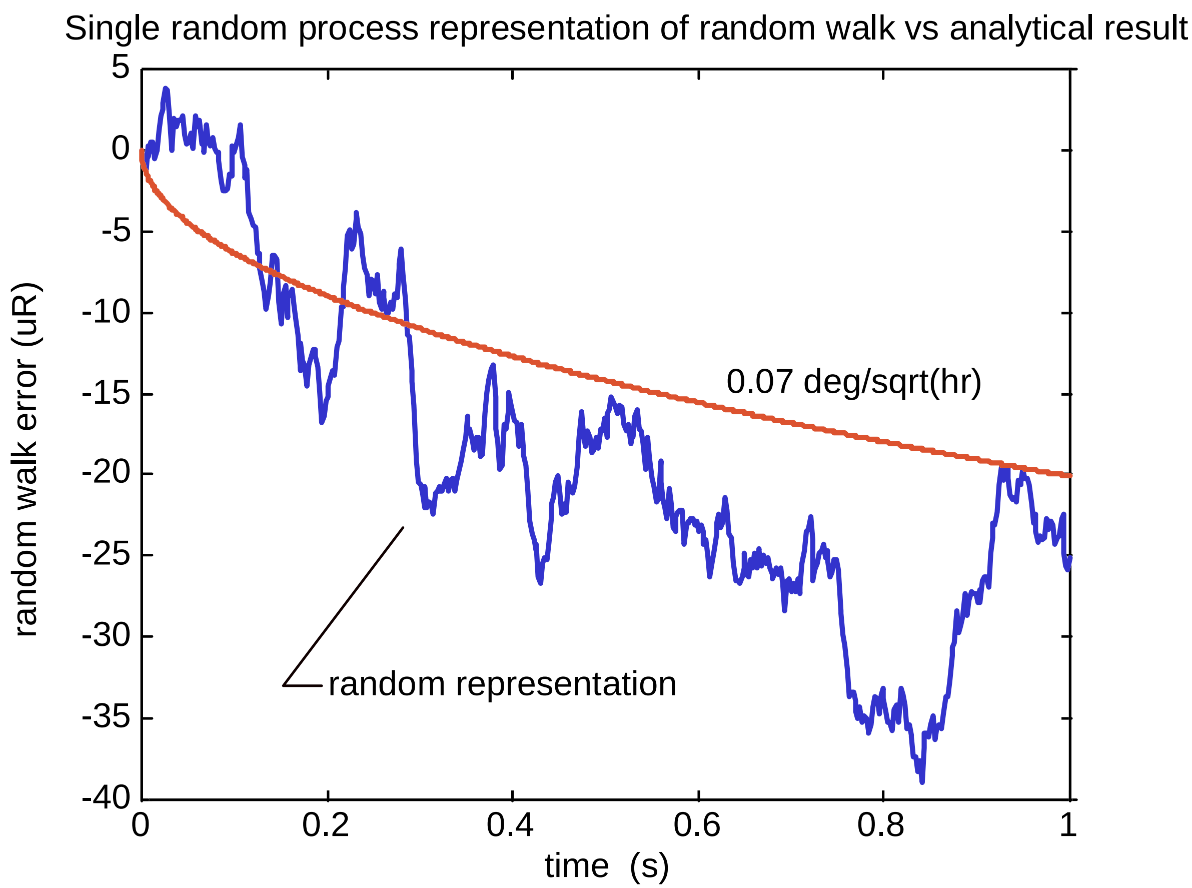


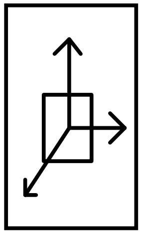
Sensor Noise Model Tool

- Spatial and temporal
  - Spatial noise (fixed pattern noise) handled in TRADES.
- Optical and mechanical sensors
- General model <u>not</u> physics based - input cofficients, but plug-in can be.
- Noise types are:
  - Angle, rate (RW), and acceleration white noise
  - Angle, rate, acceleration quantization
  - Angle, rate, acceleration flicker (1/f noise)
- To be implemented with standard I/F in Matlab

One Time Series Representation of Sensor Noise for Attitude Control Gyro

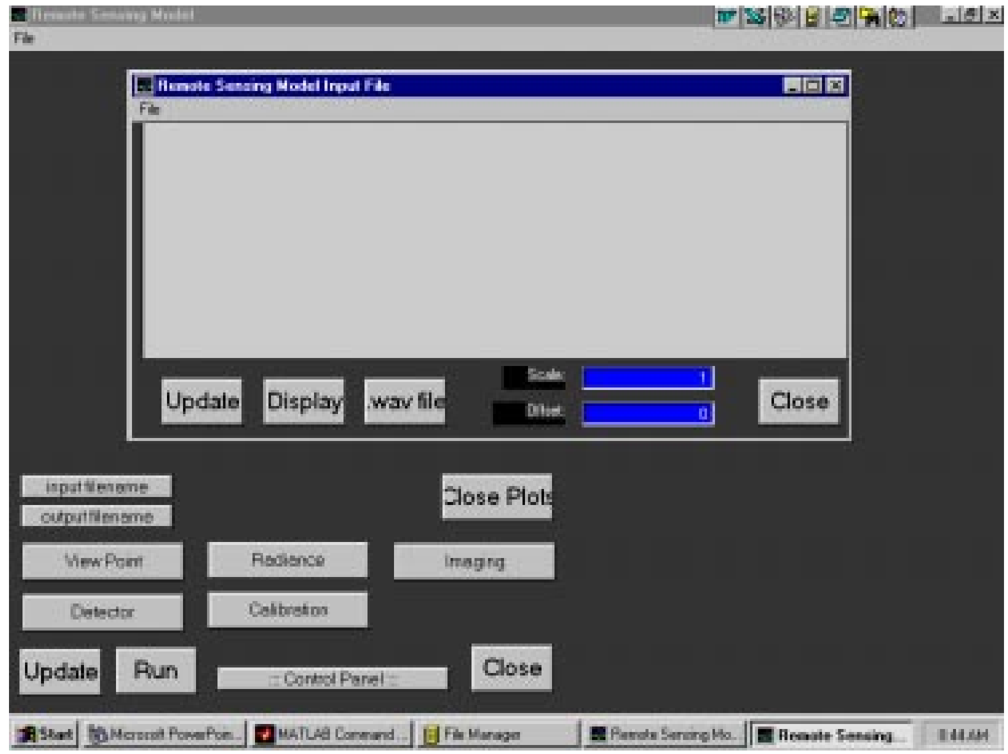
- Random walk model for LN200 fiber optic gyro





TRADES - A Toolkit for Remote-sensing Analysis, Design, Evaluation, and Simulation

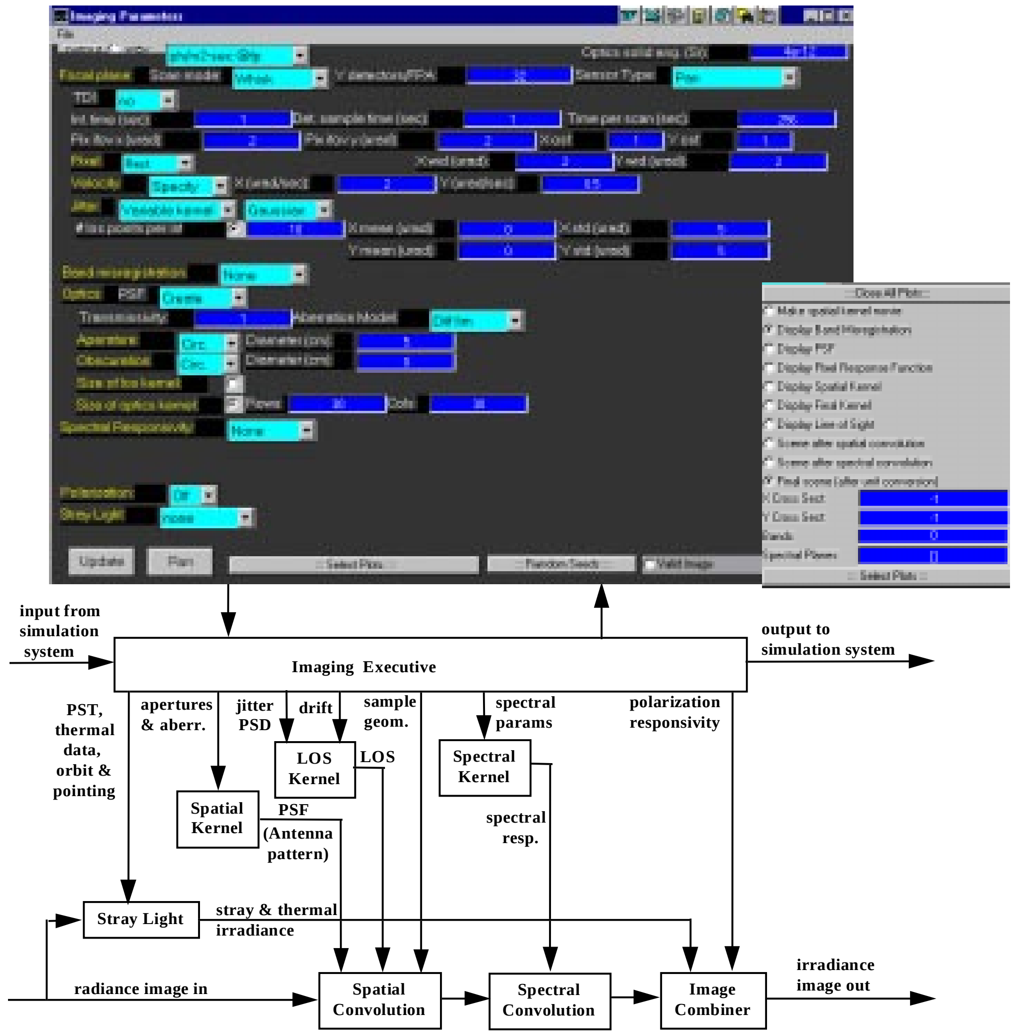
- logical division of major function supports simulation from UV thru microwave
- user-friendly GUIs facilitate rapid construction of simulations
- extensive plotting and display capability
- modules are independent
- algorithms and math models developed for simulations will be extended to design and performanace analysis tools
    - orbit & scan coverage and revisit
    - atmospheric radiative transfer
    - net system MTF analysis
    - radiation effects on charge transfer
    - SNR analysis
    - radiometric accuracy analysis



Imaging Module

Converts an at-aperture radiance image to blurred at-detector irradiance

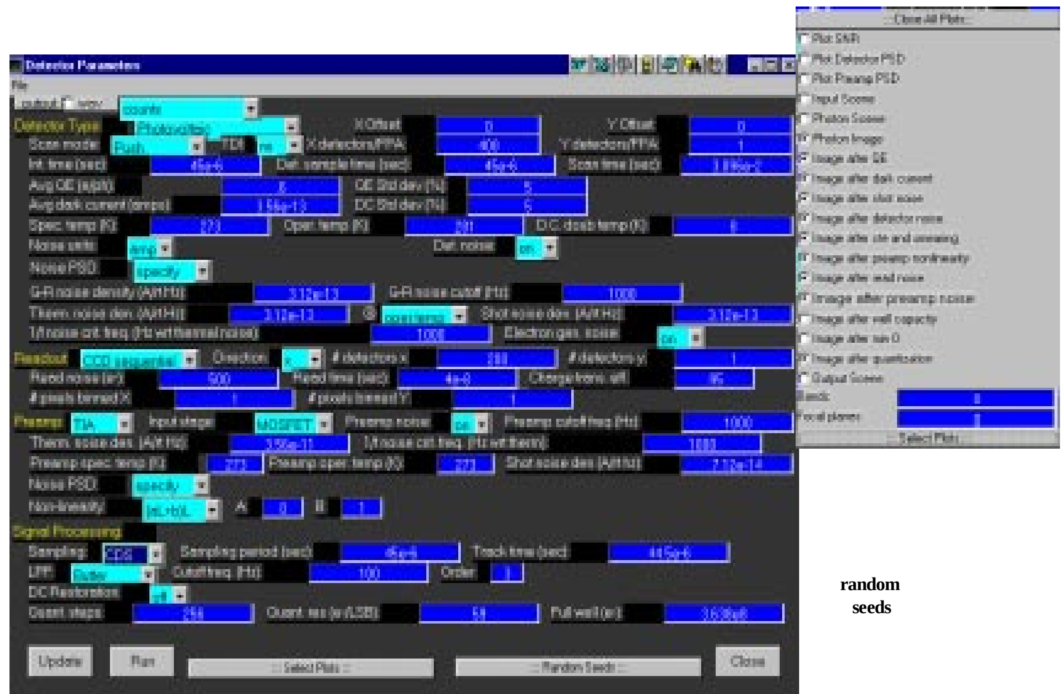
- **PSF or antenna pattern internally generated or from file**
- **Aberrations represented by Zernike polynomials**
- **LOS drift from orbital and Earth motion**
- **LOS jitter generated from jitter PSD**
- **grating spectrometer and spectral filters simulated (others to be added)**
- **stray light model using the APART PST**
- **H and V polarization sensitivities (to be added)**
- **band misregistration included**
- **numerous PSF and image displays**

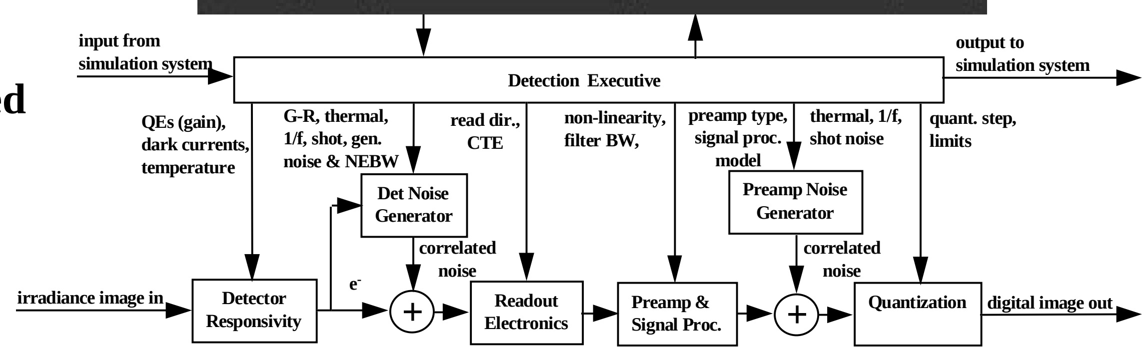


Detection Module

Simulates the detection, readout, quantization

- includes “fixed-pattern” noise in QE and dark current with temp dependence
- detailed model of detector noise includes correlated noise
- charge transfer efficiency in CCDs and read smear is simulated
- preamp non-linearities (two types)
- signal processing includes CDS, S/H and DC restore
- structured noise for detector/ preamp configurations generated from PSDs
- numerous plots for noise PSD, transfer funtions, image display





Optical Point Spread Functions with Aberrations are Easily Generated